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COMPLETE SPECIFICATION

Method and Apparatus for Electrolysis of Hydrochloric Acid

We, HOOKER CHEMICAL CORPORATION, a Corporation organized and existing under the laws of the State of New York, United States of America, of Niagara Falls, State of New York, United States of America, do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

THIS INVENTION relates to an apparatus and a method for the electrolysis of hydrochloric acid.

Hydrochloric acid is a by-product of numerous chlorination procedures, and as such it must be disposed of by sale or further chemical reaction. It is often desirable to form more useful and salable products from hydrochloric acid by converting it to hydrogen and chlorine. The demand for chlorine is such that it is readily disposed of by sale or used in further chlorination reactions.

Various electrolytic cells for the electrolysis of hydrochloric acid are known, but have only achieved limited commercial acceptance. This is most likely due to the slow development of a good commercial cell, the fluctuating demand for such a cell due to varying market conditions, the limited use thereof and the high investment cost for such cells. The electrolysis of hydrochloric acid presents many unique problems because of the highly corrosive electrolyte used and the acidic environment existing in an operating cell.

It is an object of this invention to provide an electrolytic cell for the decomposition of hydrochloric acid to hydrogen and chlorine. Another object of this invention is to provide a method for the electrolysis of hydrochloric acid in an electrolytic cell having a graphite anode and a cathode of steel, nickel plated steel or nickel alloy.

According to the present invention, there is provided an electrolytic cell for the electrolysis of hydrogen chloride divided by a porous diaphragm of synthetic plastics material into an anode chamber having anode means made of graphite and a cathode chamber having cathode means made of steel, nickel plated steel or a nickel alloy, and provided with a cell cover and a pipe made of synthetic plastics material communicating with the cathode chamber for the withdrawal of depleted catholyte.

The present invention provides also a method of producing hydrogen and chlorine in an electrolytic cell having graphite anode means and cathode means made of steel, nickel plated steel and a nickel alloy comprising: feeding an aqueous solution of hydrochloric acid and alkali metal chloride into the anode chamber of the cell, passing the feed solution through a porous plastics diaphragm separating the anode means from the cathode means, maintaining an anolyte pH of less than one, imposing a decomposition voltage across the electrodes to yield chlorine at the anode and hydrogen at the cathode, and withdrawing a depleted catholyte from the cell.

The cell of the present invention will next be described to show preferred details of construction.

The anode means typically comprises a plurality of graphite anodes connected electrically to each other; the cathode means similarly comprises a plurality of metal cathodes which may each be part of a single member. As is usual in such cells, the anodes and cathodes are interleaved. The cell is made up of a base plate, normally of concrete, to which the anodes are secured, a centre portion to which the cathodes are secured and a cover for sealing the cell. It is preferred to secure the anodes to the base plate, using a conductive metal such as lead,

copper or bronze to hold the anodes in position. The conductive metal is in electrical communication with the exterior of the cell, but is sealed from the interior of the cell by an inert non-conductive material so as to eliminate leakage of electrolyte to the base plate during cell operation. Sealants such as asphalt, polyester resins, polyvinyl chloride, polytetrafluoroethylene, and like compositions inert to hydrochloric acid, chlorine gas and temperatures up to one hundred degrees centigrade are used. The seal is complete with respect to the concrete and conductive metal such that in an assembled condition neither concrete nor metal is exposed to electrolyte.

The centre portion of the cell houses the electrodes and is preferably constructed of steel. As a precautionary measure against an accidental excess of hydrogen chloride being present in the catholyte, the cathode section may be plated with nickel or a nickel alloy or may be constructed entirely of a nickel alloy. Since the entire centre portion of the cell is protected cathodically, as described hereinafter during electrolysis, the centre portion of the cell need not be sealed from the electrolyte.

Also, attached to the centre portion of the electrolytic cell and communicating therethrough with the cathode chamber is a perc pipe through which depleted electrolyte is withdrawn from the cell and so regulates the liquid level in the cathode portion of the cell. The perc pipe is normally not cathodically protected and, therefore, it is preferable to use an inert plastic or other non-conductive chemically resistant material. Plastics similar to those used in the cell cover are preferably used in the construction of the perc pipe, especially polyesters, phenolic resins and epoxy resins, used with or without reinforcing. The perc pipe is a pipe through which catholyte percolates from the cell, and is vented to prevent siphoning and is adjustable to be raised or lowered so that the level of catholyte can be varied at will.

The top portion of the cell is constructed of concrete or metal such as iron or steel. The internal surface of the cell cover, i.e. the underside which in use faces the interior of the cell, is coated with a plastics material resistant to chlorine gas and hydrogen chloride. The plastic coating is applied so as to adhere permanently to the cover or is used as a preformed removable insert for the cover, or a combination of both methods may be employed.

Several acid and chlorine resistant plastic materials have been found to be suitable protective liners for the cell cover. Reinforced, non-reinforced or filled polyesters, phenolic resins, polytetrafluoroethylene, polypropylene, polyethylene and polyvinyl chloride have been found to be suited for this appli-

cation. Polyesters manufactured by Hooker Chemical Corporation under the tradename of HETRON (R) are particularly suitable. Alternatively, there may be applied to the internal surface of the cell cover a covering comprising rechlorinated polyvinyl chloride, which is the product of treating polyvinyl chloride (chlorine content e.g. 57%) to raise its chlorine content.

Instead of lining or coating a concrete or steel cell cover with plastic material inert to the environment existing in the cell, a cover constructed entirely of reinforced polyester, reinforced epoxy resin, or the like inert materials mentioned in the preceding paragraph can be used. When using a cell cover constructed entirely of polyester or the like material, it is preferred to provide a means of securing the cell cover to the cell. The light weight construction such as that provided by a polyester is often insufficient to provide a secure seal to prevent electrolyte leakage without a fastening means or additional weight to hold the cover in place.

The electrodes of the present invention comprise anodes constructed of graphite and cathodes constructed of steel, steel mesh, nickel-plated or nickel alloy-plated steel mesh, or nickel alloy mesh. The mesh construction is preferred in that mesh provides a ready exit for the hydrogen gas evolved. Normally, it is not necessary to use nickel plated steel or a nickel alloy, but it is often desirable as an additional protective measure. A nickel or nickel alloy construction is more corrosion resistant than steel and will retard corrosion of the cathode if an unusually high concentration of hydrochloric acid should inadvertently reach the catholyte.

The term "nickel alloy" as used herein indicates an alloy of iron with at least a nominal amount of nickel, generally more than 1% nickel. Interposed between the graphite anode means and the steel cathode means is an electrolyte-permeable plastic diaphragm. The diaphragm is preferably a woven synthetic fabric prefabricated or tailored to fit the cathode means like a glove. Suitably the cathode means is a single annular member of special cross-section, being formed with a plurality of substantially parallel internally projecting elements which are each hollow so that catholyte which is between the centre portion of the cell and the annular member can enter each hollow element. The porous diaphragm is then fitted to the inner face of the annular member so as to separate the outer face of each hollow element from an adjacent anode. The woven diaphragm can be further defined in terms of water porosity. The weave, fibre size and other characteristics are such so as to provide a fabric having a water porosity of 0.01 to 2.0 gallons per minute per square foot,

using a constant liquid pressure equal to ten inches of water.

The diaphragm, then, is constructed of woven synthetic fabric which is acid and chlorine resistant at temperatures up to one hundred degrees centigrade. Materials such as polytetrafluoroethylene, polypropylene, polyvinyl chloride, chlorinated polyvinyl chloride, mixed halogenated polymers and non-halogenated polymers, resistant to the environment are preferred. The portion of the diaphragm covering the uppermost portion of the cathode need not be porous, and it is even preferred that it be non-porous to prevent hydrogen gas produced at the cathode from rising through the diaphragm. If a highly permeable diaphragm is used the uppermost portion of the cathode must be non-porous while with a less permeable diaphragm, i.e. one that would require several inches of hydrostatic lead in the anolyte to provide adequate flow through the diaphragm, the upper portion need not be impermeable.

The cell is operated in a continuous manner by the addition of hydrochloric acid solution and replenishing amounts of sodium chloride. The start-up procedure for the cell is somewhat modified from normal operation in that the normal feed stream is not used. During start-up, the cathode must be protected from contacting excess hydrogen chloride and therefore the electrolysis commences with an alkali metal chloride solution. Hydrochloric acid is then added so as to reduce the anolyte pH to less than one. The addition rapidly neutralizes the alkali metal hydroxide produced in the catholyte during the initial start-up and reduces the pH of the catholyte to an acidic condition. Having commenced electrolysis by imposing a decomposition voltage across the cell, chlorine is liberated at the anode and hydrogen is liberated at the cathode. The feed mixture is then regulated so as to comprise a saturated solution of sodium chloride and a 5 to 20 percent hydrochloric acid solution. The hydrochloric acid addition is regulated so as to maintain in the catholyte up to 20 grams per liter hydrochloric acid or a pH of less than 7.

During the operation of the cell, hydrochloric acid and recycled sodium chloride solution is fed into the cell so as to flow from the anode to the cathode and, subsequently, be withdrawn through the perc pipe as a depleted electrolyte. The concentration of hydrochloric acid fed to the cell is regulated so as to maintain hydrochloric acid concentration of less than about 20 grams per liter in the catholyte. Regulation of the hydrogen chloride content in the catholyte is readily effected by observation of the cell voltage from which the hydrochloric acid content of the catholyte can be determined

and changed when desired. The cell voltage is directly related to the pH of the catholyte. At low pH's the reaction voltage is lower than at higher pH's. Thus, by using a potentiometer to control the flow of hydrochloric acid in the feed liquor, the amount of hydrochloric acid in the catholyte is readily maintained at a preferred level. This flexibility in the supply of feed liquor permits the use of a wide range of hydrochloric acid concentrations which can be automatically regulated in the feed stream according to the reaction voltage.

It has been found that the presence of small amounts only of hydrochloric acid in the catholyte as described has several distinctive advantages in the present electrolysis procedure. The more important advantages are the lack of chlorate formation, a higher anode efficiency resulting in lower graphite consumption and a lower cell voltage than that obtained in chloralkali cells.

The cell voltage varies as a function of the acidity of the catholyte. A low pH results in lower voltages while increasing pH values result in higher voltages. It is therefore preferred to operate the present cell with a low catholyte pH. Under such conditions, the cell efficiency is extremely high, being capable of producing chlorine at a lower kilowatt-hour rate per pound of chlorine than the most efficient chlor-alkali cells.

Highly efficient operation of the present cell is effected over a wide range of current densities. Amperage in the range of 0.5 to 3.0 amps per square inch have been found to be particularly useful and are preferred, and even more may be used.

The alkali metal chloride present in the feed solution serves to maintain the electrolyte highly conductive and this permits a reduction of the hydrogen chloride concentration to a low level in passing through the cell. Efficient operation of the cell is therefore aided by the presence of the highly ionized alkali metal chloride.

As a means of further protecting the cathode so as to provide for the use of more concentrated hydrochloric acid solutions, a corrosion inhibitor can be used. It has been found that amines are suitable corrosion inhibitors which do not interfere with the electrolysis. The amines particularly useful as corrosion inhibitors under electrolysis conditions are short chain primary, secondary and tertiary amines, and short chain primary, secondary and tertiary hydroxyl amines, wherein the short chain is from 1 to 6 carbon atoms. Tertiary amines, especially trimethylamine, triethylamine, tripropylamine, trimethanolamine, triethanolamine and tripropanolamine are preferred. The inhibitor when used is used in an amount ranging from one gram per liter to 15 grams per liter of feed liquor. A suitable combined feed liquor

for the hydrochloric acid cell described, contains from 5 to 20 percent hydrogen chloride, 1 to 20 percent alkali metal chloride, 0.1 to 1.5 percent by weight inhibitor with substantially the remaining percentage generally being water.

The method and apparatus of this invention will be further described with reference to the drawings in which:

FIG. 1 is a schematic representation of a cell, combined with a flow sheet illustrating the method of this invention;

FIG. 2 is a partially cutaway isometric, diagrammatic view of an electrolytic cell of this invention;

FIG. 3 is a partial sectional view of the cathode means shown diagrammatically in Figure 2; and

FIG. 4 is an isometric view of a cathode with part cut away for clarity.

Figure 1 shows the essential elements of an electrolytic cell 10, comprising a graphite anode 12, and a steel cathode 14, separated by a porous, woven plastic diaphragm 16. The cell 10 has an inlet 18 for acidic electrolyte, an outlet 20 for depleted electrolyte, an anolyte chamber 22, having an outlet 24 for chlorine gas and a catholyte chamber 26 having an outlet 28 for hydrogen gas produced in the catholyte chamber 26. The anolyte level 30 is slightly higher than the catholyte level 32, thereby producing a slightly forced flow of electrolyte through the diaphragm 16 from the anolyte chamber 22 to the catholyte chamber 26. Chlorine gas is produced at the anode 12 and hydrogen gas is produced at the cathode 14 by imposing a decomposition voltage across the electrodes.

Depleted electrolyte 34 flows from the catholyte chamber 26 to replenishing zone 36 where it is replenished with hydrochloric acid and resaturated with alkali metal chloride. Potentiometer 38 measures the cell voltage and thereby regulates the flow of concentrated hydrochloric acid 40 to replenishing zone 36 by controlling valve 41 in response to a cell voltage signal. The replenishment of brine is nominal and is controlled by constant or periodic additions of saturated brine 42 through valve 43. Properly replenished electrolyte from replenishing zone 36 flows through temperature regulator 44 wherein the acidic electrolyte is heated or cooled as may be required so as to result in the desired electrolyte temperature within cell 10 of fifty degrees centigrade to one hundred degrees centigrade. Lower temperatures can be used being limited only by practical operating rates. The electrolyte then flows via line 46 to re-enter cell 10 at inlet 18.

It will be noted that the present process is a continuous cyclic process wherein all the products are gaseous, e.g., chlorine and hydrogen. The replenishment of brine or

alkali metal chloride within the system is relatively small because alkali metal hydroxide is not produced and alkali metals are not removed from the system.

The apparatus of this invention is more fully described by reference to FIGS. 2, 3 and 4. The electrolytic cell of this invention comprises a base plate or bottom 48 to which are secured graphite anodes 50 by means of a conductive metallic material 52 such as lead, copper or brass. The conductive metal is preferably poured in molten form about the base of the anodes 50, thereby securing them in position while also forming a low resistance connection to an external bus bar 51. A sealant 54 is placed over the conductor so as to completely seal the conductor 52 and cell bottom 48 from electrolyte.

The center section 56 of cell 10 houses a cathode shown in Figure 3 as an annular member having internal finger-like projections 58 and lined internally with a diaphragm 16. The internal portion of the finger-like projections 58 is hollow, permitting the passage of gas and electrolyte there-through. Fitting securely about and around the finger-like projections 58 is the porous plastic diaphragm 16, the upper portion of which is a non-porous plastic material 60 such as woven plastic fabric that has been fused to a non-porous state. This provides a sealed channel within which hydrogen gas collects and flows to an outlet; the non-porous portion 60 preventing leakage to the anolyte chamber. Between centre portion 56 and member 58 is the cathode chamber; within member 58 is the anode chamber. The anodes 50 project upwardly in the anode chamber from base plate 48, and each anode is disposed between two finger-like projections 58 which are individual cathodes. The cathode 58 is welded to the centre portion 56 and is thus held in position, and is also thus electrically connected to the centre portion 56 to which the cathode lead is attached. Centre portion 56 is thus protected cathodically from the electrolyte.

Projecting from the centre section 56 is the perc pipe 62 which regulates the level of catholyte 32 in the catholyte chamber 26. The perc pipe 62 is constructed of a corrosion resistant material as previously described. Also projecting from centre section 56 is hydrogen gas outlet 28 which communicates (by means not shown) with the hydrogen channel formed by portion 60.

The top of the cell 10 is covered by cell top 64 having a liner 66 of a plastics material as previously described which covers the internal surface of the cell top and prevents gaseous chlorine and anolyte from contacting parts of cell top 64 which are not inert to chemical attack. Projecting from cell top 64 is the chlorine gas outlet 24, electrolyte inlet 18 and the sight glass 68. Sight glass 68 per-

mits observation of the anolyte level 30 in the anolyte chamber 22.

The following Examples illustrate certain preferred embodiment in the present invention. Unless otherwise indicated all parts and percentages are by weight and all temperatures are in degrees centigrade.

EXAMPLE 1

Using the electrolytic cell illustrated in FIG. 2 comprising graphite anodes and steel mesh cathodes, a woven polypropylene diaphragm having a water porosity of 0.9 gallons per minute per square foot at 10 inches of water pressure was fitted securely about the cathode. A reinforced polyester cell top liner constructed of HETRON 72 (R), manufactured by Hooker Chemical Corporation, was molded into the concrete cell top. The cell was so constructed as to prevent exposure of the concrete cell bottom to electrolyte and the concrete cell top to chlorine gas and electrolyte.

Cell operation was commenced by charging an 8 percent sodium chloride solution to the cell and applying a current density of 0.8 ampere per square inch, equal to 30,000 amperes, to the electrodes. Having commenced electrolysis, an acidic feed solution comprising 12 percent hydrogen chloride, 8 percent sodium chloride and 0.5 percent triethanolamine was fed into the anolyte chamber at a rate of 1.4 gallons per minute. The alkaline condition which developed in the cathode chamber on start-up was rapidly reduced to an acidic condition having a pH of about 1 and a hydrogen chloride content of 3.0 grams per liter. The cell voltage was

2.1 volts, the pH of the feed solution was less than 1. Chlorine was produced at the anode at a rate of 85.7 pounds per hour while hydrogen was produced at the cathode.

Depleted catholyte withdrawn from the catholyte chamber was replenished with hydrochloric acid to a 12 percent concentration using 24 percent hydrochloric acid solution and was resaturated with sodium chloride, using a 16 percent sodium chloride solution. Additional amine was added to retain a 0.5 percent level. The replenishing feed solution was then recycled to the cell for further decomposition of hydrochloric acid

EXAMPLES 2 to 13

Changes in operating current density and the effect of hydrogen chloride concentration in the catholyte were studied to determine the effect on the cell voltage and to establish the preferred operating conditions. The experiments were conducted using a laboratory cell constructed as illustrated in FIG. 1, operating with a feed solution of 12 percent hydrogen chloride and 8 percent sodium chloride at a temperature of 98.5 degrees centigrade ± 0.5 degrees centigrade. Nickel plated steel mesh cathodes and graphite anodes were used, spaced so as to provide a one-fourth inch electrode gap. A polypropylene diaphragm having a porosity of 1.0 gallon of water per minute per square foot at 10 inches of water pressure, was inserted between the electrodes so as to restrict the flow of electrolyte from the anode to the cathode. The results for a series of experiments under the stated conditions are tabulated in Table I.

Table I

Example Number	Current Density (Amps per in ²)	HCl Catholyte Concentration (grms/liter)	Cell Voltage Volts
2	3	0.40	3.87
3	3	1.46	3.28
4	3	2.94	2.74
5	2	0.73	2.93
6	2	2.70	2.64
7	2	3.67	2.25
8	1	0.73	2.51
9	1	2.70	2.00
10	1	3.85	1.90
11	0.87	1.04	2.42
12	0.87	3.31	1.92
13	0.87	5.00	1.83

From Examples 2 to 13 it is readily seen that highly efficient cell operation is achieved over a wide range of current densities. It is also seen that lower cell voltages are obtained under the more acidic catholyte conditions as indicated by the concentration of HCl in the catholyte.

The method of the Example 1 was re-

peated varying the feed concentrations of hydrochloric acid between 5 percent and 20 percent, and varying the temperature between about 50 degrees centigrade and 100 degrees centigrade. Various amine inhibitors, including trimethylamine, triethylamine, trimethanolamine and triethanolamine, were used in amounts ranging from 1 gram per

liter to 15 grams per liter feed solution. In all processes, the feed rate of electrolyte to the anolyte chamber was controlled so that the amount of HCl in the catholyte did not exceed about 20 grams per liter. The examples were also repeated using woven (polytetrafluoroethylene, and rechlorinated polyvinyl chloride as the diaphragm fabric. Nickel plated steel mesh and nickel alloy mesh were also used as the cathode. It was found that the care in start-up and shut-down of the electrolytic cell to prevent acid attack on the cathode did not have to be as great when using nickel plated steel mesh or nickel alloy as the cathode material.

In all of the tests conducted, using the variables and within the ranges described, the hydrochloric acid cell of this invention functioned extremely efficiently.

While there have been described various embodiments of the invention, the apparatus and methods described are not intended to be understood as limiting the scope of the invention, as it is realized that changes therein are possible.

In our co-pending application no. 21181/68 (Serial No. 1,132,282) we claim a concrete cover for an electrolytic cell to the internal surface of which is applied a protective covering comprising chlorinated polyvinyl chloride.

WHAT WE CLAIM IS:—

1. An electrolytic cell for the electrolysis of hydrogen chloride divided by a porous diaphragm of synthetic plastics material into an anode chamber having anode means made of graphite and a cathode chamber having cathode means made of steel, nickel plated steel or a nickel alloy, and provided with a cell cover and a pipe made of synthetic plastics material communicating with the cathode chamber for the withdrawal of depleted catholyte.

2. An electrolytic cell as claimed in Claim 1, wherein the cathode means are of mesh construction and the plastics diaphragm is constructed of polypropylene, polytetrafluoroethylene, or chlorinated polyvinyl chloride and is shaped to fit securely about the mesh cathode.

3. An electrolytic cell as claimed in Claim 2, wherein the diaphragm is woven synthetic fabric.

4. An electrolytic cell as claimed in Claim 2 or 3, wherein the cathode means comprise a metal member formed with a plurality of substantially parallel projections each of which in use constitutes a cathode and the anode means comprise a plurality of graphite anodes each disposed between a respective pair of cathodes.

5. An electrolytic cell as claimed in Claim 4, wherein the anodes are each secured to a concrete base of the cell and are connected

electrically to each other and to a conductor by a conductive metal.

6. An electrolytic cell as claimed in any preceding Claim, wherein the cell cover is a concrete cell having applied to its internal surface an acid resistant plastic material selected from polyester, reinforced polyester, phenolic resin, polytetrafluoroethylene, polypropylene, polyethylene, polyvinyl chloride.

7. An electrolytic cell as claimed in any of Claims 1 to 5, wherein the cell cover has applied to its internal surface a protective covering comprising re-chlorinated polyvinyl chloride.

8. An electrolytic cell as claimed in any preceding Claim, wherein the plastic diaphragm is of a material having a water porosity of 0.01 to 2.0 gallons per minute per square foot per 10 inches of water pressure.

9. An electrolytic cell constructed, arranged and adapted to operate substantially as hereinbefore described with reference to and as illustrated in Figures 2 to 4 of the accompanying drawings.

10. A method of producing hydrogen and chlorine in an electrolytic cell having graphite anode means and cathode means made of steel, nickel plated steel and a nickel alloy comprising: feeding an aqueous solution of hydrochloric acid and alkali metal chloride into the anode chamber of the cell, passing the feed solution through a porous plastic diaphragm separating the anode means from the cathode means, maintaining an anolyte pH of less than one, imposing a decomposition voltage across the electrodes to yield chlorine at the anode and hydrogen at the cathode, and withdrawing a depleted catholyte from the cell.

11. A method as claimed in Claim 10, wherein the aqueous solution comprises by weight 5 to 20 percent hydrogen chloride, 1 to 20 percent alkali metal chloride and water.

12. A method as claimed in Claim 10 or 11, wherein the feed solution has a pH of less than 1 and the depleted catholyte has a pH of less than 7.

13. A method as claimed in Claim 10, 11 or 12, in which the aqueous solution of hydrochloric acid is saturated with an alkali metal chloride and contains an inhibiting amount of a corrosion inhibitor.

14. A method as claimed in Claim 13, wherein the corrosion inhibitor is an amine selected from the group consisting of primary, secondary and tertiary amines and hydroxyl amines having a short chain of up to 6 carbon atoms.

15. A method as claimed in Claim 13 or 14, wherein the inhibitor is used in an amount of 1 gram to 15 grams per liter of feed solution.

16. A method as claimed in Claim 13, 14 or 15, in which the aqueous solution con-

tains by weight 5 to 20 percent hydrogen chloride, 1 to 20 percent sodium chloride and 0.1 to 1.5 percent amine inhibitor.

- 5 17. A method as claimed in Claim 16, in which there is obtained a depleted catholyte containing less than 20 grams per liter hydrogen chloride from the cell.

- 10 18. A method for producing hydrogen and chlorine in an electrolytic cell having nickel alloy mesh cathode means and graphite anode means comprising feeding an aqueous solution of hydrochloric acid and alkali metal chloride having a pH of less than 1 into the electrolytic cell, passing the aqueous solu-

tion through a woven plastic diaphragm separating the anode and the cathode, imposing a decomposition voltage across the electrodes to yield chlorine at the anode and hydrogen at the cathode, and withdrawing a depleted catholyte from the cell. 15 20

19. A method of producing hydrogen and chlorine by electrolysis of hydrochloric acid, substantially as hereinbefore described.

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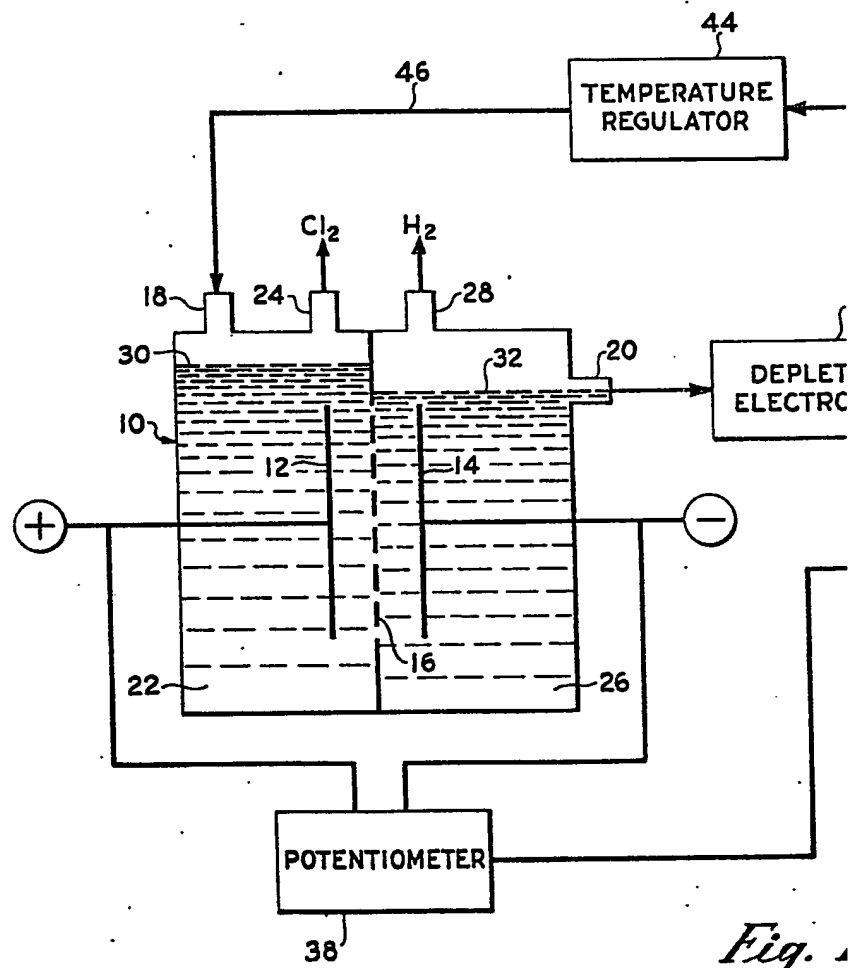


Fig. 1

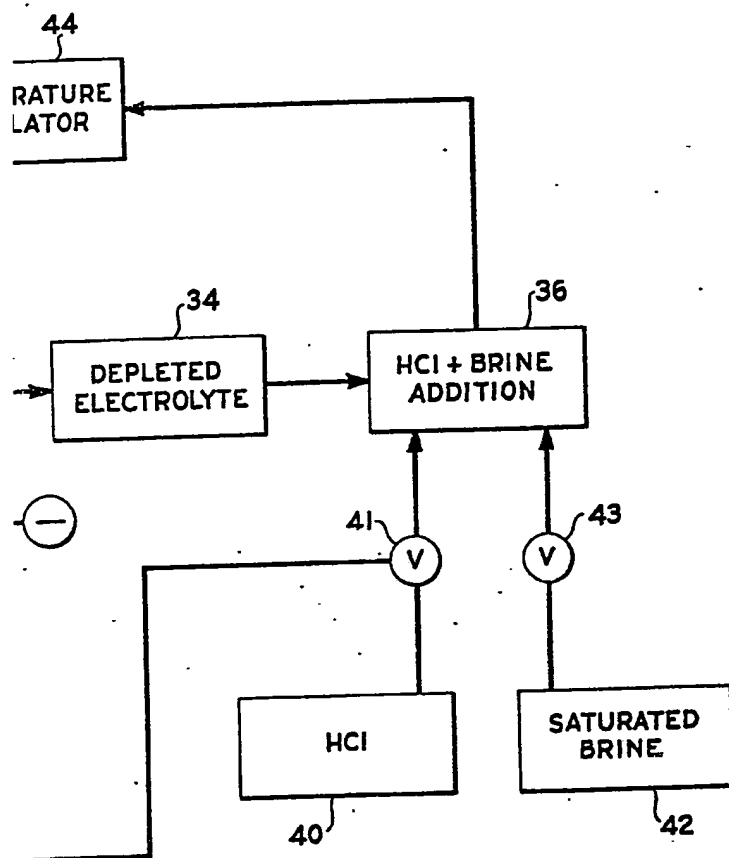


Fig. 1

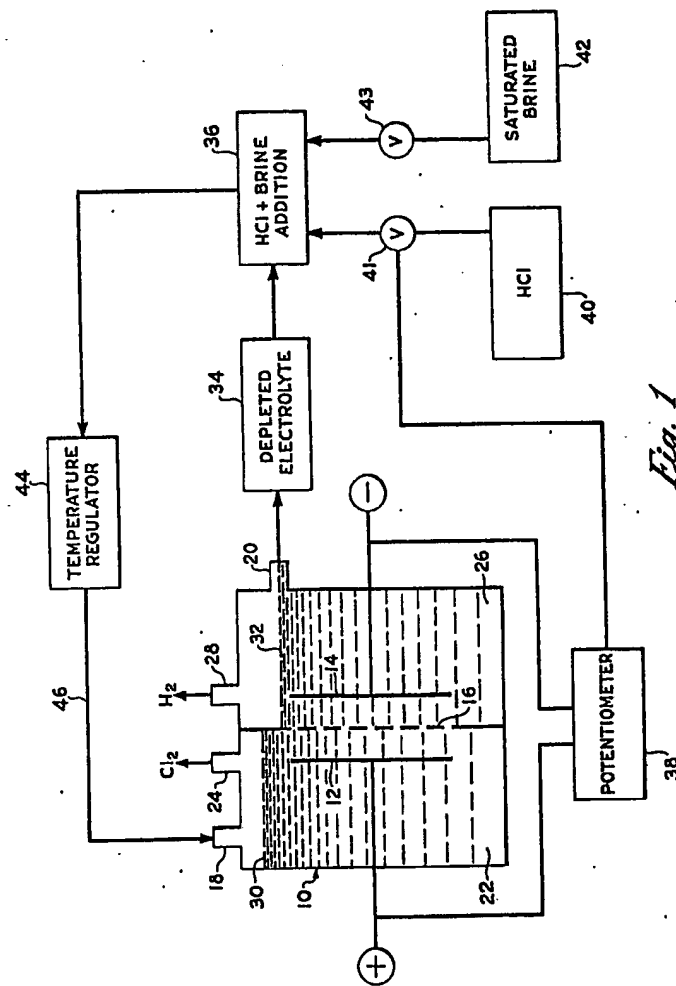
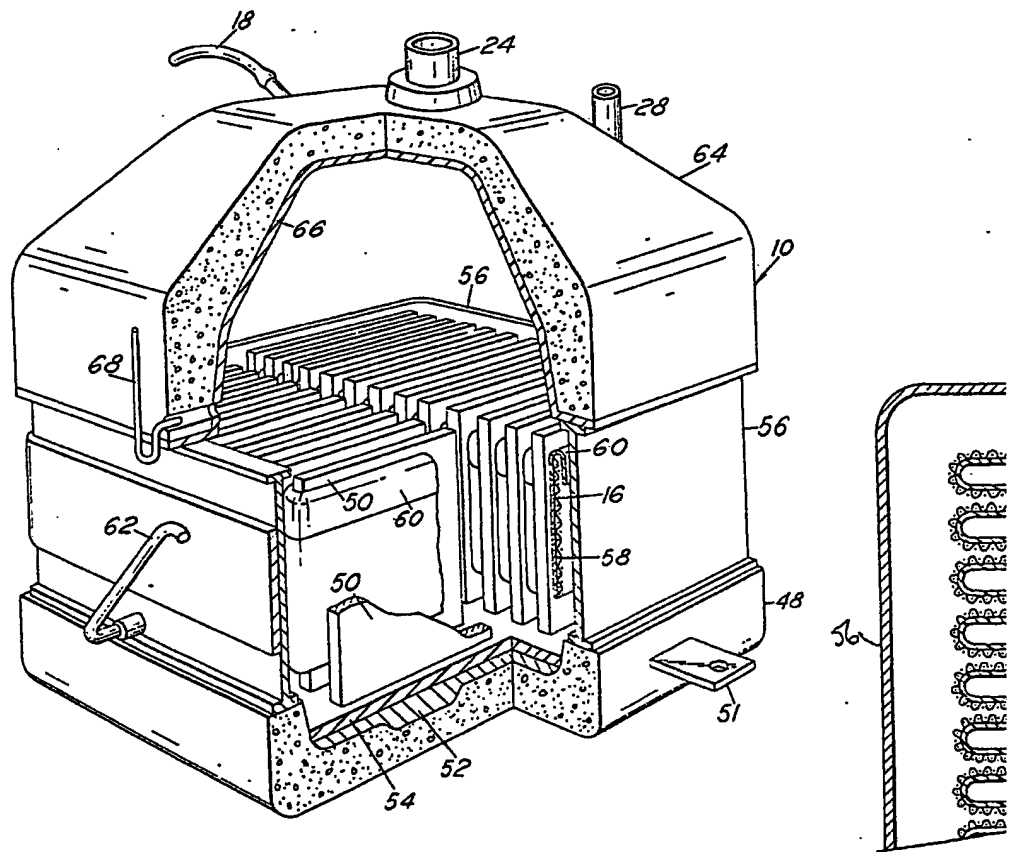


Fig. 1

Fig. 2



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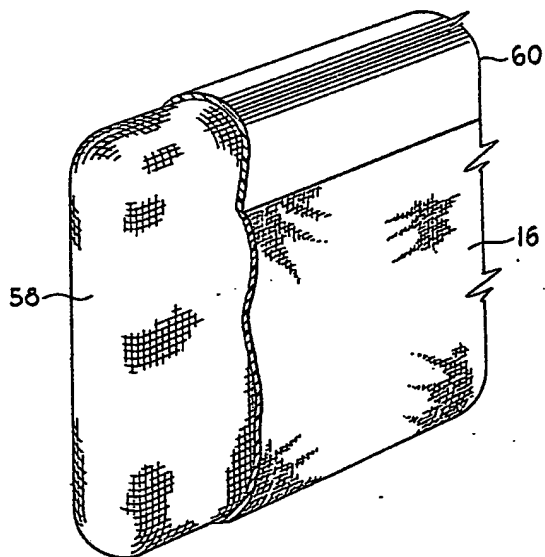


Fig. 4

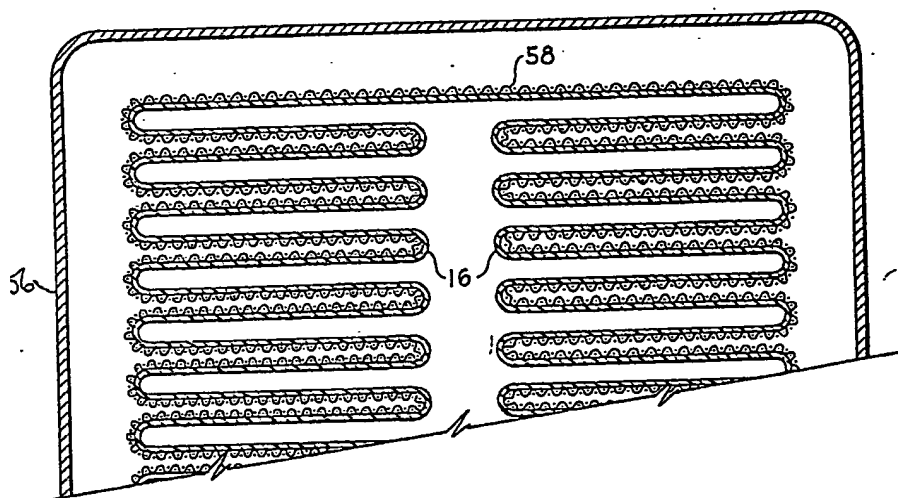


Fig. 3

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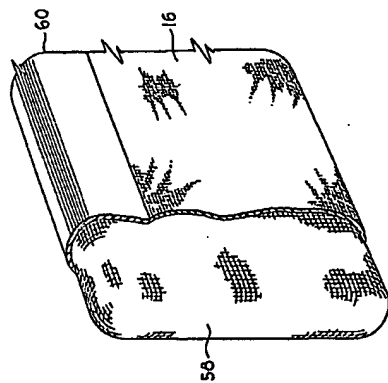


Fig. 2

Fig. 3

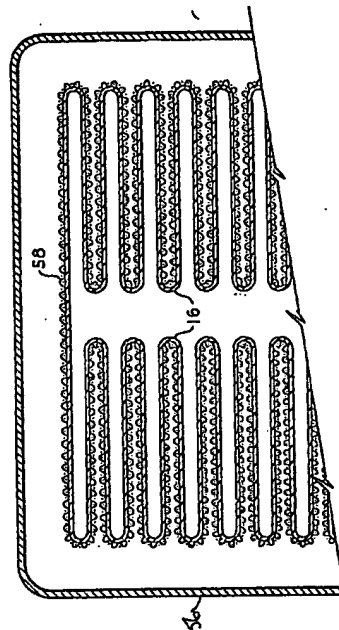
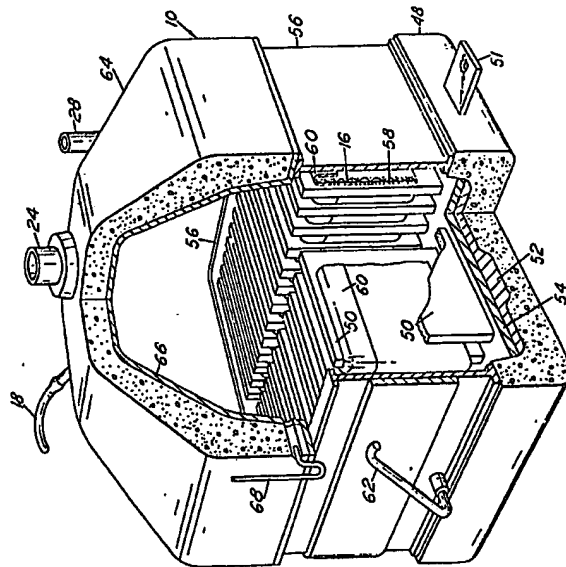


Fig. 4

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